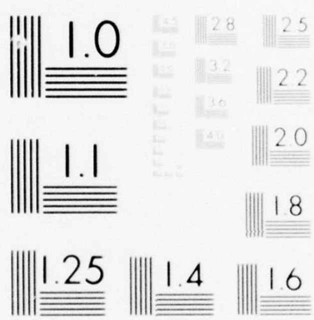
AD-A043 039 MASSACHUSETTS INST OF TECH CAMBRIDGE DEPT OF NUCLEAR--ETC F/G 13/2
ENERGY PRODUCTION BY SOLID WASTE INCINERATION.(U)
APR 77 S B GOLDMAN, F R BEST, M W GOLAY DAAK02-74-C-0308

UNCLASSIFIED USAFESA-RT-2036 NL

| OF |
AD
A043039

END
DATE
FILMED
9-77
DDC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

ADA043039

(12)

FESA-RT-2036

ENERGY PRODUCTION BY SOLID WASTE INCINERATION

Steven B. Goldman
Frederick R. Best
Michael W. Golay
Department of Nuclear Engineering
Massachusetts Institute of Technology
Cambridge, MA 02139

30 April 1977

Final Report

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

Prepared for:

US ARMY FACILITIES ENGINEERING SUPPORT AGENCY
Research and Technology Division
Fort Belvoir, VA 22060

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER FESA-RT-2036	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Energy Production by Solid Waste Incineration		5. TYPE OF REPORT & PERIOD COVERED Topical Report Jun 76 - Apr 77
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Steven B. Goldman, Frederick R. Best, Michael W. Golay		8. CONTRACT OR GRANT NUMBER(s) DAAK02-74-C-0308
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Nuclear Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 6.27.31; 4A762731AT41; T6; 013
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Facilities Engineering Support Agency, Research and Technology Division, Fort Belvoir, VA 22060		12. REPORT DATE 30 Apr 77
		13. NUMBER OF PAGES 28
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Energy; Energy Production; Solid Waste

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Topical Report.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

18 11 19 9 Final 6 10 15 17 16 11 12 34p.

401186 4B

ABSTRACT

The purpose of this study is to assess the potential of utilizing solid waste as a viable source of energy. A technical description of the process is given, followed by a detailed economic analysis. Finally, the applicability of such a facility for U.S. Army installations is presented.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

TECHNICAL ASPECTS OF UTILIZING ENERGY FROM SOLID WASTE

1.1 Introduction

The technology to recover energy from solid waste is not new. The generation of electricity from refuse had been used successfully in England in 1900.[1] In America, however, the high capital costs of such a facility coupled with the large tracts of land available for inexpensive sanitary landfill all but stopped the development of this energy source. Furthermore, "cheap" energy was available through oil.

Today the situation has altered. We are generating an ever increasing amount of solid waste. Sanitary landfill can no longer continue at the previous rate due to lack of land near large urban centers. And, of course, energy is no longer cheap. Consequently interest is being renewed in the thermal processing of solid waste, both as a source of energy and as a means of refuse disposal.

There are three major processes that convert solid waste into useful energy: incineration with heat recovery; fuel recovery; and pyrolysis.

This report examines the incineration process, in Section 1.2 following. Section 1.3 discusses briefly, for completeness, fuel recovery and pyrolysis.

1.2 Energy Recovery by Incineration

Historically, incineration has been the traditional competitor to landfill in areas of insufficient suitable landfill capacity within an economic haul distance.[2] Ordinary incinerators utilize a refractory furnace where the solid waste is burned with air, and the resultant heat and waste gases are

dumped into the atmosphere. The unburned and unburnable solid residues are placed in nearby landfills. Unfortunately most of the incinerators built in the United States do not practice energy recovery, as has been done in Europe and Japan[3] for some time. Now, however, the feasibility and profitability of recovering energy has been proven[4] and currently no less than 20 projects of this type are being operated or planned in the U.S.[2]

Figure 1.1 shows a flow chart of recovering useful energy from solid waste. This chart is "generically typical" in that most solid waste energy plants will follow this scheme to some extent, depending of course on the specific facility's economic and design requirements.

The remainder of this section will examine each of the steps in Figure 1.1, and end with a discussion of solid waste as fuel.

1.2.1 <u>Solid Waste Collection, On-site Receiving.</u> Estimates show[5,6] that the national commercial and industrial refuse generation rate is approximately 1 ton per person per year, and that this will increase to about 1.5 tons per person per year by the year 2000. Conservation and recycling efforts will probably not affect these figures. Therefore, a nominal 2000 tons per day (TPD) plant would require the refuse of 730,000 persons, i.e., a medium sized city or metropolitan area. Presumably, then, the refuse is available.

Conventional collection methods are utilized to bring this refuse on site.

1.2.2 <u>Size Reduction.</u> Size reduction consists of reducing the size of bulky waste to allow the manageable handling of this waste further downstream. This is accomplished by crushing, shearing, shredding, cutting and/or pulverizing the waste as required. Many kinds of machines exist and operate for this purpose.

1.2.3 Pre-combustion Separation. The physical separation of the refuse flow stream into various component flow streams is effected for various reasons. The main purpose in this case is to separate those materials, e.g., metals and glass, which do not contribute to the combustion process. Another purpose is materials recovery. Table 1.1 shows typical municipal solid waste compositions. Potentially valuable materials which can be salvaged from the waste stream include glass, rubber, metals and plastics. An economic credit can be realized from the recovery and subsequent sale of these materials.

Although solid waste separation is a rapidly evolving technology, techniques with fairly high separation efficiencies do now exist. In fact, facilities are now in operation[2] in which materials recovery is the primary product and energy is a by-product. The interested reader is referred to References 2, 7 or any recent book on materials recovery.

1.2.4 Storage. The storage of the processed solid waste generally occurs near the furnace-boiler. With such an arrangement, an overhead crane can feed refuse from the storage area into the furnace charging hopper. The capacity of the storage area must be sized such that contractual output demands are met during periods when little or no refuse is being delivered.

1.2.5 Furnace-Boiler. A number of steam generating systems can be employed.[2] This report will concern itself with the watertube wall boiler, which is similar to that in a conventional fossil-fired power station design.

Trash, taken by crane from a storage pit and loaded into the refuse hopper, goes down the chute and onto the furnace grates. These reciprocating grates keep the trash in motion for complete combustion. Ash is discharged to a water-sealed hopper and removed. Primary combustion air is introduced by

a fan beneath the grates. Secondary combustion air is introduced above the grates to help complete combustion and to control flue gas temperature. The upper section of the furnace, i.e., the boiler, consists of watertube walls, the superheater, economizer, and steam drum.

Typical operating characteristics are given in Table 1.2.

1.2.6 Auxiliary Boiler. In order to assure that steam is available, auxiliary boiler(s) usually fired by oil are required to meet steam demands during downtimes, anticipated or otherwise. These standby boiler(s) can be packaged, pre-engineered systems available from selected equipment manufacturers, and can be tied into the main steam line. Similarly an auxiliary burner can be attached to the combustion chamber where it can be used to ignite, augment, or provide combustion.

1.2.7 Gaseous Emissions Control. Even a modern, well-designed and properly operated incinerator cannot meet federal and most, if not all, state regulations for particulate emissions without an effective air pollution control system. Commercially available devices which can bring emissions levels to within required standards exist. These include electrostatic precipitators, and scrubbers similar to the equipment used in fossil fueled electrical generating stations.

1.2.8 Post-Combustion Separation and Effluent Control. Incinerator residue consists of the solid materials remaining after combustion. Residue may contain ash, glass, metals, rocks, and unburned organic substances. Gaseous emissions control residues are those particulates removed by the air pollution control equipment. Both of these residues must be disposed of properly. Generally solid residues are interred in sanitary landfill, although separation for materials recovery may occur prior to disposal.

Process water, discharged from wet scrubbers, residue quenching, water jackets and the like, must be treated to meet federal, state, and local discharge water quality standards.

1.2.9 Energy Utilization. As seen in Table 1.2, a good quality steam can be generated. This can be put to many uses. The most obvious use of the recovered steam is in the thermal processing plant itself. Steam turbines can drive large pumps, fans, small electric generators, and other equipment that would otherwise require large amounts of externally supplied power. This "energy recycle" could keep operating costs down, although the initial capital costs would be high.

The idea of using steam for district heating and cooling is not new, having been practiced in Europe for many years. It is, however, novel in the U.S. One plant of this nature now operating is in Nashville, Tenn., where it heats and cools major downtown buildings.(2) Additionally, a recent study for Onondaga County, N.Y. strongly supports a solid waste fueled energy plant to service 65 university, hospital, local, and federal buildings.(8)

Process heat for industry is another alternative. The privately owned Resco Company facility in Saugus, Mass. supplies the nearby General Electric Company with between 65,000 and 350,000 lbs/hr of steam.(4) This steam is used for electrical generation, space heating, and equipment operations.

The use of refuse for the generation of electricity is rare in the U.S. However, a trash fueled 110 MW steam turbine electrical generating station has contracted to sell to Jersey Central Power and Light Co. nearly 1 billion kilowatt-hours of electricity per year.(9) Indications point to an increased economic attractiveness of this concept.

1.2.10 Solid Waste as Fuel. Because the composition of refuse varies greatly as shown in Table 1.1, and because many different

substances with differing heating values are found in refuse, the heating value has been found to vary greatly. References (2) and (5) indicate a range of 3000 to 6500 Btu/lb, and the literature surveyed tends to use a nominal value of 5000 Btu/lb. This compares with nominal values of 14,000 Btu/lb for natural gas, 18,000 Btu/lb for oil, and 11,500 Btu/lb for coal.

The sulfur content of refuse is low in comparison to that of coal and oil. Data[5] show a consistent average sulfur content of refuse in the 0.1% to 0.2% range. This contrasts with a range of 2.5% to 3.5% in bituminous coal. Furthermore, 95% to 100% of the sulfur in coal will appear in the flue gas as oxides; in refuse only 25% to 50% of the input sulfur is released as SO_2. Thus, burning solid waste has a significantly smaller impact on air quality than coal or oil. Refuse can be considered a low-sulfur fuel.

1.3 Fuel Recovery and Pyrolysis

Fuel recovery is the recovery of thermal energy by burning processed solid waste as supplemental fuel in existing boiler furnaces. This concept has proven successful, for example, in the well documented City of St. Louis/Union Electric Co. Project.[2,5]

Pyrolysis is a process in which organic material is decomposed at elevated temperature in a relatively oxygen-free atmosphere. The process is enclothermic, i.e., requiring heat either directly or indirectly. The products of pyrolysis are normally a complex mixture of combustible gases and liquids, and solid residues. The fluid products are potentially useful as fuels. Several pyrolysis processes have been developed, and some full scale plants are in operation.

Figure 1.1 Flow Chart of Thermal Processing Facility

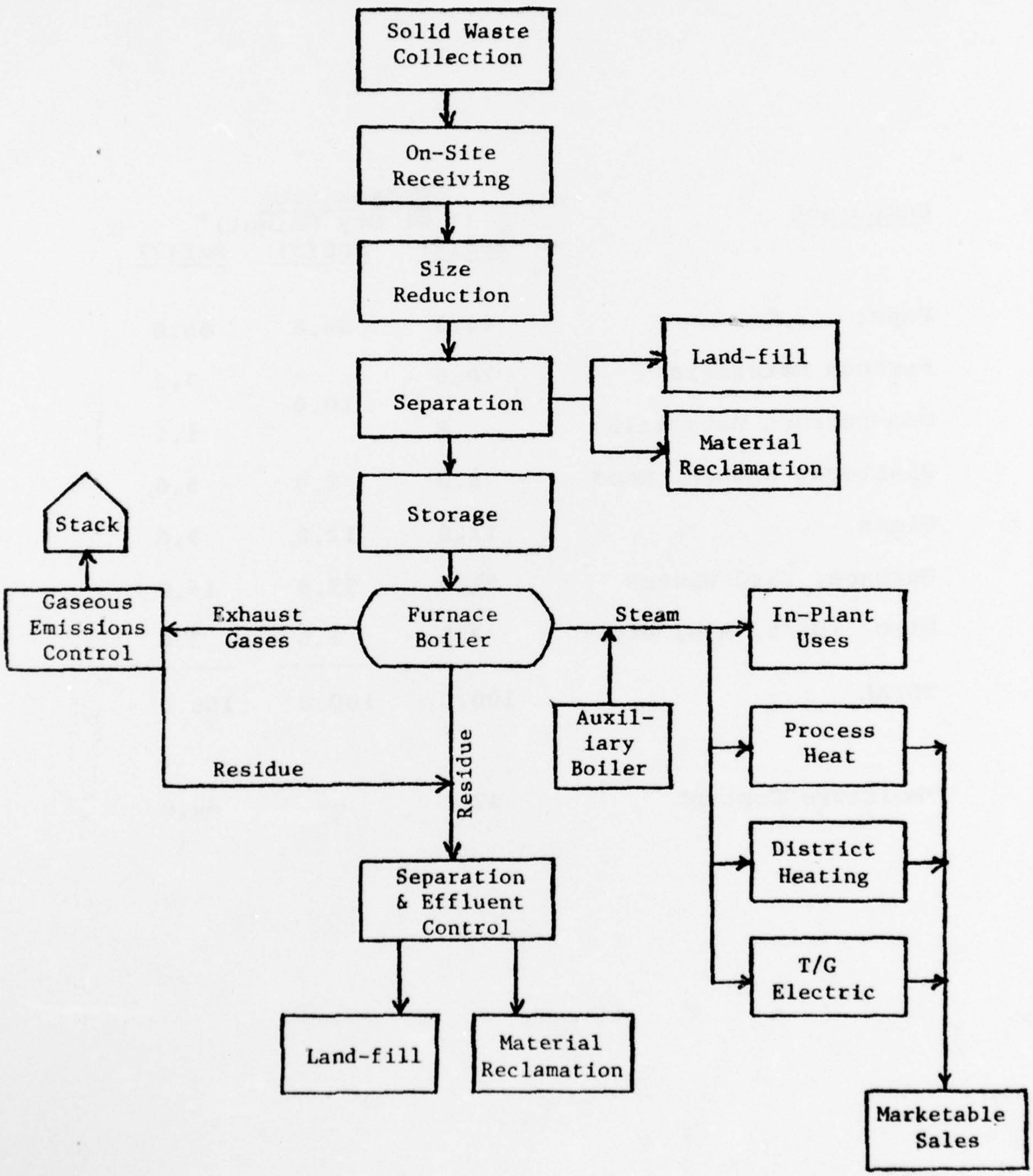


Table 1.1 Typical Compositions of U.S. Refuse.

Component	Composition (% of Dry Weight)* Ref(2)	Ref(5)	Ref(7)
Paper	45.0	38.0	55.0
Ferrous Materials	10.5	10.0	7.5
Non-ferrous Materials	.8		1.5
Plastics, Rubber, Wood	8.8	2.0	5.0
Glass	11.0	12.0	9.0
Garbage, Yard Wastes	21.4	32.0	19.0
Misc. (Dirt, Ash, etc.)	2.5	6.0	3.0
TOTAL	100.0	100.0	100.0
*Moisture Content	27.0	--	30.0

Table 1.2 Operating Characteristics of Refuse Fired Steam Generating Plants

Item	Resco-Saugus	NW Chicago	Incin-3 Montreal	Harrisburg Penn.
# Boilers	2	4	4	2
Nominal Refuse Capacity (TPD)	1200	1600	1200	720
Steam Production (1000 lb/hr)	185	110	100	92.5
Steam Pressure (Psig)	690	275	225	250
Steam Temperature (^{O}F)	875	414	500	456
Startup Date	1975	1970	1970	1972
Reference	(4)	(5)	(5)	(5)

Chapter 2

ECONOMIC ASPECTS OF UTILIZING ENERGY FROM SOLID WASTE

2.1 Approach

The purpose of this section is to develop an economic analysis of a refuse-fueled power plant similar to that described in Chapter 1. Two types of energy product are studied: superheated steam and electricity. In addition, two methods of financing are analyzed: privately owned and operated, and municipally owned and operated.

As has been stated in Chapter 1, the technology for these facilities is proven, but reliable economic data are scarce. Therefore, based on a literature survey, an economically composite facility is analyzed as follows:

1. *Design the facility.* -- The thermal processing plant of Figure 1.1 is the general reference design. The plant burns 2000 tons per day (TPD) of solid waste; recovers energy in the form of superheated steam; and recovers salable raw materials as a by-product.

2. Develop economic data. -- Cost estimates are taken from literature, tabulated, and adjusted. From this, costs are assigned for the facility under study.

3. Calculate levelized costs of energy generation. -- Clearly, in order to economically justify this project, the levelized unit costs of the energy product must be lower than the unit costs of other methods of power production.

4. Compare these results with the unit costs of other energy sources.

2.2 Development of Economic Data

As stated previously, reliable current economic data are scarce. Table 2.1 is a compilation of data found in various sources. Most of the data are from feasibility studies made in 1971 which obviously are unreliable now. A good source of information is Ref. (4), which describes the Resco Company facility in Saugus, Mass., currently the only privately owned and operated refuse burning plant in the United States. This plant generates steam which is sold to a nearby General Electric Co. industrial complex.

Rather than rely completely on the Resco data, adjustments were made to the data of Table 1.2 to see if a correlation could be found. The adjustments made were the following:

1. Using the Marshall & Swift (M&S) Indexes[11] transform the data for capital cost, operation and maintenance (O&M), and sales revenue into 1975 dollars.
2. Scale by TPD using the "Law of 7/10's"* the capital cost and O&M (since O&M is generally a function of plant size) to 2000 TPD, and
3. Scale steam production and sales revenue proportionally to the appropriate TPD level in the year 2000.

---

*The "law of 7/10's"[10] is the mathematical equation which quantitatively expresses the well-recognized engineering principle, economy of scale. The equation is of the form

$$I = I_o \left(\frac{K}{K_o}\right)^n$$

where

K = size (i.e. rating) of unit under study
K_o = size of reference unit for which cost is known
I = capital cost of unit under study
I_o = capital cost of reference unit
n = scale exponent, which has been found to be 0.68 ($\approx$7/10) for most power generating systems

Sample Calculation. A partial example, using the Weinstein & Toro[2] capital cost data, is shown below:

1974 M&S Index = 398.4

1975 M&S Index = 445.0

** Cost Adjustment Multiplier = (445.0/398.4) = 1.117

Stated Capacity = 1000 TPD

Desired Capacity = 2000 TPD

** Scale Multiplier = $(2000/1000)^{.68} = 1.602$

1974, 1000 TPD Capital Cost = $\$15.5 \times 10^6$

Therefore, the 1975, 2000 TPD Capital Cost is

$$(\$15.5 \times 10^6)(1.117)(1.602) = \$27.74 \times 10^6$$

These resulting adjusted cost data are tabulated in Table 2.2.

Notice that in the feasibility studies cited (i.e., not the Resco project) the data for capital cost agree within a relatively close range. This is also true for the O&M costs and steam production rates. Revenues, however, vary widely. This may be explained by the fact that sales revenues were based on the projected market price of the product (the projections having been made at the time of the study), and not on the actual costs of generation. In view of the price variations in energy in recent years, these revenue data should be ignored.

Note that the capital cost of the Resco plant is almost twice as great as the estimated costs of the other designs. The Resco capital cost is based on actual costs, which is much more reliable than the feasibility study data which are projected costs. Reference (9) quotes a $\$66 \times 10^6$ capital cost for a 4000 TPD facility. Scaled to 2000 TPD, this capital cost would be $\$41.2 \times 10^6$. Therefore, the 2000 TPD facility analyzed in this report will have a capital cost of $\$50 \times 10^6$ (1976 dollars).

Table 2.3 lists the data which will be used in the economic analysis. Some specific comments follow.

A nominal 600,000 lb/hr value for generated superheated steam is used, based on the expectation that future boilers will be designed to be more efficient than current boilers by utilizing the experience of the latter. For O&M costs, an average value of $\$3.2 \times 10^6$ is used.

The estimate of materials credit is based upon an assumption of 7% by weight of refuse of recovered, salable materials, at $10 per ton of material recovered.[3,4]

The turbine-generator (T/G) and associated systems are assigned costs as follows:

Example. Size of T/G calculation --

$$\text{Fuel consumption rate} = 2000\,\frac{\text{tons}}{\text{day}}\cdot\frac{1\text{ day}}{24\text{ hr}}\cdot\frac{2000\text{ lb}}{\text{ton}}$$

$$= 1.667 \times 10^5\ \text{lb/hr}$$

$$\text{Heat consumption rate} = 1.667\times10^5\ \frac{\text{lb}}{\text{hr}}\cdot 5000\frac{\text{Btu}}{\text{lb}}\cdot .70\ \begin{matrix}\text{boiler}\\ \text{efficiency}\end{matrix}$$

$$= 5.8333 \times 10^8\ \text{Btu/hr}$$

$$\text{Size of T/G} = 5.833\times10^8\ \frac{\text{Btu}}{\text{hr}}\cdot\frac{1\text{ Kw}\cdot\text{hr}}{3412\text{ Btu}}\cdot\frac{1\text{ Mw}}{10^3\text{Kw}} \simeq 171\ \text{Mwt}$$

Example. Cost of T/G calculation --

From Ref. (12), a 3860 Mwt T/G plant costs $\$239 \times 10^6$ in 1976. Scaling this to 171 Mst, the additional T/G capital costs would be $\$239 \times 10^6\left(\frac{171}{3860}\right)^{.68} = \$28.7 \times 10^6$.

Note that this value is the busbar capital cost, exclusive of transmission equipment capital costs.

The boiler efficiency is 70%.[2,5,6] The capacity factor is 85%, based on operation 6 of 7 days per week, full shift; i.e., 24 hours a day. Since the steam generated is superheated, a nominal 40% efficiency is assumed for the T/G balance of plant for electrical generation, when analyzed.

The cost of fuel analysis has an interesting aspect. If a city or group of cities builds a refuse burning plant, they effectively have the fuel on hand. Now, since trash collection

and disposal are generally a city function regardless of refuse use, these disposal costs can be considered "sunk" costs and not applicable to the fuel cost analysis. Municipal garbage trucks can deliver the "fuel" to the station; thus in this case, and herein for the municipal owned facility analysis, the fuel cost is considered zero.

This is not the case for a privately owned facility. A private organization can charge a city for the "privilege" of delivering its solid waste to the facility. This is the mode of operation for the aforementioned Resco project. Resco charges its clients $13 per ton of refuse delivered. This is a contractual arrangement which escalates yearly according to government price indices and which imposes stiff economic penalties upon the clients for not delivering the specified tonnage. Thus Resco makes money on its fuel even before it is delivered. On the other hand, this relationship can be economically advantageous to a city. Resco must accept its contracted deliveries, whether or not the facility generates energy. As such, the city is out of the solid waste disposal/ sanitary landfill "business." This can be a potential savings in many ways for a city.

Note that this fuel cost analysis is very sensitive to the specific plant site. In some areas, notably rural, refuse collection is not a municipal function, and fuel supply arrangements need to be negotiated. The fuel cost for a municipality owned station could be negative if, for example, city A (which owns such a facility) charges city B and city C to dispose of B's and C's solid wastes. Another treatment of fuel costs could be as an internal cash flow, where for example City A's Power Department charges its Public Works Department for trash disposal. Although both departments work for the same city, this could be advantageous in the accounting practices. The power station might be forced to pay for fuel if, say in the preceeding example, the internal cash flow is

not advantageous to the Power Department. Additionally, a privately owned station might have to compete with other users of trash for the fuel supply required. Analyses need to be made for each site proposed.

Returning now to the discussion of data used in the economic analysis, power generation is assumed to be constant throughout the plant life of 30 years. Steam generation, at 600,000 lb/hr and a capacity factor of 85%, is 4.4928×10^9 lb/yr. Electrical generation, using a T/G plant efficiency of 40% and an overall capacity factor of 60%, is 3.595×10^8 Kw·hr/yr.

Financing data are chosen as typical values for a power plant project, from Ref. (10).

2.3 Calculation of Levelized Costs of Energy Generation

Table 2.3 summarizes the data which are used in the economic analyses. Levelized costs of energy production are calculated in Tables 2.4 through 2.7 under the following conditions:

Table 2.4	Investor owned - Steam generation
Table 2.5	Investor owned - Electrical generation
Table 2.6	Municipally owned - Steam generation
Table 2.7	Municipally owned - Electrical generation

All studies take credit for materials recovery sales revenue. The analysis is based on methods derived in Ref. (10). Profit is not included.

The levelized unit busbar costs are listed in Table 2.8.

Table 2.1 Compilation of Data from Literature Regarding Trash Incineration as Fuel

Facility	Saugus-Resco	Weinstein & Toro Study	Steam Gen. & Mat'l Rec. Study	Elec. Gen. Only Study	Steam Gen. Philadelphia Study	Steam Gen. Cleveland Study
Source of Data (Reference)	4	2	3	3	5	5
Date of Data	1976	1974	1971	1971	1971	1971
Plant Capacity (TPD)	1200	1000	1000	1000	1400	400
Plant Capital Costs (10^6\$)	38*	15.5	12.784	17.717	13.87	5.675
O&M Costs (10^6\$)	2.374	1.554	1.869	1.748	1.314	.679
Fuel Costs (10^6\$)	-5.865	0	0	0	0	0
Steam Production Rate (1000 lb/hr)	350	229	228	-	300	90
Annual Steam Sales (10^6\$)	4.549	2.29	1.0		-	552
Annual Mat'ls Sales (10^6\$)	.307	1.096	.535		-	-
Annual Electric Sales (10^6\$)				1.0		
Owner/Operator	Private	Municipal	Municipal	Municipal	Municipal	Municipal
Economic Life of Plant (yrs)	-	30	20	20	-	-
Financing Method	75%-7.6% bonds 25% stock	7% bonds	5% bonds	5% bonds	-	-
Assumed Fixed Charge Rate	-	-	10.9%	10.9%	13.75%	14.6%

*in 1975

Blank = not applicable; Dash = not given

Table 2.2 Adjusted Facility Cost Data
(Stated in 1976 Dollars)

Facility	Resco-Saugus	Weinstein & Toro Study	Steam Gen. & Mat'l Rec. Study	Elec. Gen. Only Study	Steam Gen. Philadelphia Study	Steam Gen. Cleveland Study
Plant Capacity (TPD)	2000	2000	2000	2000	2000	2000
Plant Capital Cost (10^6\$)	53.8	27.74	28.37	39.31	24.48	23.48
Plant O&M (10^6\$/yr)	3.36	2.78	4.148	3.88	2.32	2.81
Plant Fuel (10^6\$/yr)	-9.775	0	0	0	0	0
Steam Prod. Rate (10^3 lb/m)	583.3	458.	456.	-	430	450
Annual Steam Sales (10^6\$)	7.582	5.116	2.77		-	2.76
Annual Mat'ls Sales (10^6\$)	.512	2.448	1.482		-	-
Annual Electric Sales (10^6\$)				2.77		

Blank = not applicable; Dash = not given

Table 2.3 Composite Trash Incineration Facility Data

Factor	Magnitude	Remarks
Plant capacity	2000 TPD	
Plant capital cost	$50,000,000	1976 dollars
Capital cost of T/G Plant	$28,700,000	1976 dollars
O&M costs	$3,200,000/yr	Increases 5%/yr
Fuel cost	-$13/ton refuse	Increases 4%/yr Investor owned
	$0	Municipally owned
Materials credit	$434,400/yr	
Capacity factor	85%	Steam production
	60%	Electrical production
Boiler efficiency	70%	
T/G plant efficiency	40%	
Steam production	600,000 lb/hr	
Steam enthalpy	1500 Btu/lb	
Economic life	30 years	
Depreciation method	Straight Line	
Financing method:	Investor Owned	Municipally Owned
Bond fraction	60%	100%
Bond rate	8%	7%
Stock fraction	40%	0
Stock rate	16%	0
Tax rate	50%	0
Discount rate	8.8%	7%

Table 2.4 Levelized Unit Cost Data — Privately Owned Facility-Steam Generation

A. Levelized Required Revenue

Item ($\times 10^6$\$)

	End of Year 1	2	3	4
Remaining investment	50.	48.33	46.67	45.
1 Depreciation	1.667	1.667	1.667	1.667
2 Bond interest	2.4	2.32	2.24	2.16
3 Return on equity	3.2	3.093	2.987	2.88
4 Taxes	3.2	3.093	2.987	2.88
5 O&M	3.2	3.36	3.528	3.7044
6 Fuel	-8.0665	-8.389	-8.725	-9.074
7 Material credit	-.434	-.434	-.434	-.434
Annual required revenue = $\sum$ 1-7	5.16615	4.70965	4.24965	3.78305
Net change	-.466	-.466	-.466	

Levelized Required Revenue = 5.16615 - .466(A/G,8.8%,30)
= 1.08×10^6 \$/yr

B. Levelized Unit Energy Cost

$$= \frac{\text{Required Annual Revenue}}{\text{Annual Energy Production}}$$

$$= \frac{1.08 \times 10^6 \text{ \$/yr}}{4.4928 \times 10^9 \text{ lb/yr}} = 2.404 \times 10^{-4} \text{ \$/lb}$$

= .2404 \$/1000 lb steam

Table 2.5 Levelized Unit Cost Data — Privately Owned Facility-Electrical Generation

A. Levelized Required Revenue

Item ($\times 10^6$\$)

		End of Year			
		1	2	3	4
	Remaining investment	78.7	76.0767	73.4533	70.83
1	Depreciation	2.623	2.623	2.623	2.623
2	Bond interest	3.7776	3.65168	3.52576	3.39984
3	Return on equity	5.0368	4.86891	4.07010	4.53312
4	Taxes	5.0368	4.86891	4.07010	4.53312
5	O&M	3.2	3.36	3.528	3.7044
6	Fuel	-8.0665	-8.389	-8.725	-9.074
7	Materials credit	-.434	-.434	-.434	-.434
	Annual required revenue = $\sum$ 1-7	11.1737	10.54949	9.91977	9.28548
	Net change		-.62421	-.62972	-.63429

Levelized Required Revenue ≃ 11.1737 - .63(A/G,8.8%,30)

≃ 5.65×10^6 \$/yr

B. Levelized Unit Energy Cost

$$= \frac{5.65 \times 10^6 \text{ \$/yr}}{3.595 \times 10^8 \text{ Kw}\cdot\text{hr/yr}}$$

$$= 1.572 \times 10^{-2} \text{ \$/Kw}\cdot\text{hr}$$

$$= 15.72 \text{ mills/Kw}\cdot\text{hr}$$

Table 2.6 Levelized Unit Cost Data — Municipally Owned Facility-Steam Generation

A. Levelized Required Revenue

Item ($\times 10^6$\$)

		End of Year			
		1	2	3	4
	Remaining investment	50.	48.33	46.67	45.
1	Depreciation	1.667	1.667	1.667	1.667
2	Bond interest	3.5	3.3833	3.2667	3.15
3	O&M	3.2	3.36	3.528	3.7044
4	Fuel	0	0	0	0
5	Materials credit	-.434	-.434	-.434	-.434
	Annual required revenue = $\sum$ 1-5	7.9327	7.976	8.0274	8.0871
	Net difference	+.0433	+.0514	+.0597	
	Δ Change		+.008	+.008	

Levelized Required Revenue

$= 7.9327 + [.0433 + .008(A/G,7\%,29)](A/G,7\%,30)$

$= 9.099 \quad 10^6$ \$/yr

B. Levelized Unit Energy Cost

$$= \frac{9.099 \times 10^6 \text{ \$/yr}}{4.4928 \times 10^9 \text{ lb/yr}} = 2.025 \times 10^{-3} \text{ \$/lb}$$

= 2.025 \$/1000 lb steam

Table 2.7 Levelized Unit Cost Data — Municipally Owned Facility-Electrical Generation

A. Levelized Required Revenue

	Item ($\times 10^6$ \$)	End of Year 1	2	3	4
	Remaining investment	78.7	76.0767	73.4533	70.83
1	Depreciation	2.623	2.623	2.623	2.623
2	Bond interest	5.509	5.3254	5.1417	4.9581
3	O&M	3.2	3.36	3.528	3.7044
4	Fuel	0	0	0	0
5	Materials credit	-.434	-.434	-.434	-.434
	Annual required revenue = $\sum$ 1-5	10.898	10.874	10.859	10.8515
	Net change	-.024	-.015	-.0075	
	Δ change		+.009	+.009	

Levelized Required Revenue

$$= 10.898 + [-.024 + .009(A/G,7\%,29)](A/G,7\%,30)$$

$$= 11.969 \times 10^6 \ \$/yr$$

B. Levelized Unit Energy Costs

$$= \frac{11.969 \times 10^6 \$/yr}{3.595 \times 10^8 \ Kw\cdot hr/yr} = 3.329 \times 10^{-2} \ \$/Kw\cdot hr$$

$$= 33.29 \ mills/Kw\cdot hr$$

Table 2.8 Summary of Unit Cost Data for Energy from a Refuse Fueled Power Plant

	Steam ($/1000 lb)	Electricity (mills/Kw·hr)
Investor Owned	.2404	15.72
Municipally Owned	2.025	33.29

Chapter 3

DISCUSSION OF RESULTS AND CONCLUSIONS

The results listed in Table 2.8 show interesting trends. It is seen that even though the cost of money is higher and the effect of taxes greater for an investor-owned facility, the cost of energy generation is lower for it than for the municipally owned project. This is due to the fact that the private company can accrue revenue from its acceptance of fuel, i.e. the fuel has a negative cost. However, as is noted in Section 2.2, fuel value is site specific, subject to much analysis.

Based on steam sales, the Resco Facility sells steam at a cost of approximately \$2.50 per 1000 lb, the Boston Edison Company charges an average of \$2.00 per 1000 lb, depending on quantity and end use. Note that these are the customer's charge, not the costs of generation. As such, the cost of steam generation from a refuse-fueled plant is seen to be commercially competitive in the available United States example.

Studies in Ref. (10) show busbar electricity costs to be in the range of 25 to 35 mills/Kw·hr. Again the calculated unit costs of electricity appear to be competitive. On all studies, transmission and distribution costs are not reflected in the unit prices.

These analyses are tacitly based upon the successful marketability of the materials and energy products. Materials sales generally depend on the market price in effect at the time of recovery, and transportation costs to the buyer. Electricity can be sold to the local grid, if transmission costs are not prohibitive. Steam sales could be uncertain: there must be a local requirement for the steam. District heating is an attractive use for this product. Another

possible utilization of the steam is in an industrial capacity, as with the Resco/GE arrangement. In that situation the need for steam exists, little retrofit is required, and the plant can follow the industry's load demand. Large refuse facilities could supply the energy demands of an industrial park. In summary, the location of the project is an extremely important factor that governs the success of this venture, and careful analyses must be made to ensure a market for the facility's products.

In conclusion, the technology to recover useful energy from the incineration of solid waste is available and has been proven. The economics are favorable, especially in view of the fact that prices of energy from other sources appear unlikely to decrease in the foreseeable future. The overriding concern is the project site, where the economics of fuel sources and energy product transmission and use are the deciding factors of the plant's economic feasibility. Site-specific studies of these questions must be performed even before the design phase commences in a particular application.

Refuse as fuel is not the solution to national energy supply problems. Estimates show[6] that if all the solid waste generated in the U.S. yearly were incinerated and its energy recovered, only 10% of the U.S. heating needs could be supplied. Use of refuse as fuel is, however, a practical way of disposing of the ever increasing amount of refuse in the U.S. and at the same time utilizing its energy to conserve diminishing resources of energy producing fuels.

Chapter 4

THE POTENTIAL OF UTILIZING ENERGY FROM SOLID WASTE FOR U. S. ARMY INSTALLATIONS

The solid wastes produced on military installations are a potential source of energy. The burning of the wastes for energy would also alleviate disposal problems.

Previously cited estimates show[5,6] that the national per capita refuse generation rate is one ton per person per year. Thus, a larger Army installation (in the 50,000 person population range) would generate enough fuel for a nominal 140 TPD incineration facility. The scaling method introduced in Chapter 2 would work adversely on the economics for a plant this size, however. The capital cost of a 140 TPD steam generating facility would be $7,700,000. Consequently, a "dollars invested per TPD rating" ratio would have a value of $55,000/TPD. This compared with a $25,000/TPD amount for the example in Chapter 2. Furthermore, by using an analysis similar to the one presented in Table 2.6 (using a discount rate of 10%, however), the levelized unit energy cost for steam generation is found to be $3.62 per 1000 lb steam. This is economically unfavorable when compared to the large scale facilities of Chapter 2.

If a large incinerator facility is needed, the military base might acquire the additional fuel from nearby civilian communities through contractual arrangements. Thus, local towns would be relieved of their refuse disposal problems, and the base would have the required solid waste for a large energy plant. This concept could have good political as well as economic results. Of course, the ramifications of adopting such a concept insofar as site factors and Department of Defense policy must be addressed.

Concerns other than energy production costs may be overriding considerations in determining the feasibility of an incineration plant for a particular military installation, and comparisons with commercial ventures may be moot. For example, an Army base may have a problem with its current solid waste disposal systems or methods; an energy producing incinerator could be the solution. Or, a base may have (or be constructing) buildings which require steam service; again the steam generating incinerator could supply this service without relying upon expensive fossil fuels. Of course, these scenarios are site-specific for which feasibility studies must be done.

Further examples of utilizing an energy from solid waste facility merit consideration. Studies are currently being done concerning the feasibility of Total Energy Systems (TES) for Army bases.* A TES would supply all the electrical and thermal energy needs of a base, utilizing an electrical generating system for the former and the associated waste heat for the latter. The design size of the power station and thermal storage reservoir are determined by the magnitude of the peak load required. As such, if an incineration facility were integrated into the TES, it would supply some of the system peak load, thus decreasing the design size of the power station and thermal reservoir. One final example is that solid waste energy could provide the fuel to supplement the energy obtained from a solar energy system for heating and cooling.

In conclusion, then, energy from solid waste has much potential for use in military installations, and further detailed feasibility studies should be undertaken.

---

*For example, see "Economic and Performance Evaluation of Total Energy Supply Options for Department of Defense Installations" U.S. Army Facilities Engineering and Support Agency, Contract No. DAAK02-74-C-0308.

REFERENCES

1. Tucker, D.G., "Electricity from Town Refuse - Three Quarters of a Century Ago," Electronics and Power (January, 1976).

2. Weinstein, N. and Toro, R., Thermal Reprocessing of Municipal Solid Waste for Resource and Energy Recovery 1st ed., Ann Arbor Science Publishers, Ann Arbor, Mich. (1976).

3. Midwest Research Institute, Resource Recovery, Prepared the the Council on Environmental Quality (February, 1973).

4. Forestell, W., "Don't Bury Garbage - Generate Tax Revenues," The American City and County (May, 1976) p. 1-4.

5. Jackson, F., Energy from Solid Waste 1st ed., Noyes Data Corp., Park Ridge, N.J. (1974).

6. Wilson, M., "Heat Energy from Waste Incineration: Cash for Trash," Heating/Piping/Air Conditioning (April, 1974) v.46, p. 51-6.

7. Abert, J. et al., "The Economics of Resource Recovery from Municipal Solid Waste," Science (March, 1974) v.183, p. 1052-8.

8. Anonymous, "Solid Waste Energy," Mechanical Engineering (February, 1975) v.97, p. 42.

9. Anonymous," Solid Waste Will Fuel 110 Mw Plant," Power Engineering (August, 1975) v.79, p. 70.

10. Driscoll, M., Subject 22.34 "Economics of Nuclear Power," M.I.T. (Fall, 1976).

11. Ricci, L. "CE Cost Indexes Accelerate 10 Year Climb," Chemical Engineering (April 28, 1975).

12. Golay, M. et al., Subject 22.33 "Nuclear Reactor Design," M.I.T. (Spring, 1976).

FESA DISTRIBUTION

US Military Academy
ATTN: Dept of Mechanics
ATTN: Library
West Point, NY 10996

Chief of Engineers
ATTN: DAEN-ASI-L (2)
ATTN: DAEN-FEB
ATTN: DAEN-FEP
ATTN: DAEN-FEU
ATTN: DAEN-FEZ-A
ATTN: DAEN-MCZ-S
ATTN: DAEN-MCE-U
ATTN: DAEN-MCZ-E
ATTN: DAEN-RDL
Dept of the Army
WASH, DC 20314

Director, USA-WES
ATTN: Library
P.O. Box 631
Vicksburg, MS 39181

Commander, TRADOC
Office of the Engineer
ATTN: ATEN
ATTN: ATEN-FE-U
Ft. Monroe, VA 23651

US Army Engr Dist, New York
ATTN: NANEN-E
26 Federal Plaza
New York, NY 10007

USA Engr Dist, Baltimore
ATTN: Chief, Engr Div
P.O. Box 1715
Baltimore, MD 21203

USA Engr Dist, Charleston
ATTN: Chief, Engr Div
P.O. Box 919
Charleston, SC 29402

USA Engr Dist, Savannah
ATTN: Chief, SASAS-L
P.O. Box 889
Savannah, GA 31402

USA Engr Dist Detroit
P.O. Box 1027
Detroit, MI 48231

USA Engr Dist Kansas City
ATTN: Chief, Engr Div
700 Federal Office Bldg
601 E. 12th St
Kansas City, MO 64106

USA Engr Dist, Omaha
ATTN: Chief, Engr Div
7410 USOP and Courthouse
215 N. 17th St
Omaha, NM 68102

USA Engr Dist, Fort Worth
ATTN: Chief, SWFED-D
ATTN: Chief, SWFED-MA/MR
P.O. Box 17300
Fort Worth, TX 76102

USA Engr Dist, Sacramento
ATTN: Chief, SPKED-D
650 Capitol Mall
Sacramento, CA 95814

USA Engr Dist, Far East
ATTN: Chief, Engr Div
APO San Francisco, CA 96301

USA Engr Dist, Japan
APO San Francisco, CA 96343

USA Engr Div, Europe
European Div, Corps of Engineers
APO New York, NY 09757

USA Engr Div, North Atlantic
ATTN: Chief, NADEN-T
90 Church St
New York, NY 10007

USA Engr Div, South Atlantic
ATTN: Chief, SAEN-TE
510 Title Bldg
30 Pryor St, SW
Atlanta, GA 30303

USA Engr Dist, Mobile
ATTN: Chief, SAMEN-C
P.O. Box 2288
Mobile, AL 36601

USA Engr Dist, Louisville
ATTN: Chief, Engr Div
P.O. Box 59
Louisville, KY 40201

USA Engr Dist, Norfolk
ATTN: Chief, NAOEN-D
803 Front Street
Norfolk, VA 23510

USA Engr Div, Missouri River
ATTN: Chief, Engr Div
P.O. Box 103 Downtown Station
Omaha, NB 68101

USA Engr Div, South Pacific
ATTN: Chief, SPDED-TG
630 Sansome St, Rm 1216
San Francisco, CA 94111

AF Civil Engr Center/XRL
Tyndall AFB, FL 32401

Naval Facilities Engr Command
ATTN: Code 04
200 Stovall St
Alexandria, VA 22332

Defense Documentation Center
ATTN: TCA (12)
Cameron Station
Alexandria, VA 22314

Commander and Director
USA Cold Regions Research Engineering
Laboratory
Hanover, NH 03755

USA Engr Div, Huntsville
ATTN: Chief, HNDED-ME
P.O. Box 1600 West Station
Huntsville, AL 35807

USA Engr Div, Ohio River
ATTN: Chief, Engr Div
P.O. Box 1159
Cincinnati, OH 45201

USA Engr Div, North Central
ATTN: Chief, Engr Div
536 S. Clark St
Chicago, IL 60605

USA Engr Div, Southwestern
ATTN: Chief, SWDED-TM
Main Tower Bldg, 1200 Main St
Dallas, TX 75202

USA Engr Div, Pacific Ocean
ATTN: Chief, Engr Div
APO San Francisco, CA 96558

FORSCOM
ATTN: AFEN
ATTN: AFEN-FE
Ft. McPherson, GA 30330

Officer in Charge
Civil Engineering Laboratory
Naval Construction Battalion Center
ATTN: Library (Code L08A)
Port Hueneme, CA 93043

Commander and Director
USA Construction Engineering
Research Laboratory
P.O. Box 4005
Champaign, IL 61820

D — 73.280 — AG — Ft Belvoir